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RESEARCH ARTICLE

Hydrogeochemistry of Natar and Cisarua Hot springs in South Lampung, Indonesia

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Abstract

Natar Hot Spring is one of the geothermal manifestations that is located in Lampung Province, Indonesia. About 6 km to the east, another hot spring appears with temperature around 40°C with neutral pH called Cisarua Hot Spring. The Natar Hot Spring itself having temperature 47-54°C with 6.23 pH. Based on the geologic map, the appearance of these hot spring is caused by Lampung-Panjang Fault which trending northwest-southeast. Morphology of the research area is showing a flat terrain topography which composed of Quaternary volcanic rock and metamorphic rock in the basement. The nearest volcano that expected to be the heat source of the geothermal system is the Quaternary extinct volcano called Mt. Betung which is located about 15 km to the southwest. The aim of the study is to analyze the geochemistry of the manifestations and calculate the reservoir temperature. Geochemistry analysis result shows both manifestations are bicarbonate which is formed as a steam-heated water or steam condensates. Geothermometer calculation shows that the geothermal reservoir has temperature 150-160°C with approximately 300 m in depth. All manifestations are originated from meteoric water according to stable isotope analysis D and δ18O data and interacting with carbonate-metamorphic rock beneath the surface based on 13C isotope value. A further geophysics study is needed to determine where the heat comes from.

Keywords: geochemistry, hot spring, Natar, Cisarua, Lampung, isotope, geothermometer.

1. Introduction

Indonesia has abundant of geothermal resources, until 2014, it is recorded that total potential of geothermal energy in Indonesia exceeds 28,9 GWe (Girianna, 2014). One of the areas which have geothermal spot is located in South Lampung Regency, Lampung Province, Indonesia. Its existence is well-known because of the presence of geothermal surface manifestation in the form of hot spring which used as a bathing place. There are two groups of hot spring in the research area, i.e. Natar hot spring and Cisarua hot spring. Both are located in Natar district, precisely 4 km in the east of Natar City and 15 km in the north of Bandar Lampung City.

Preliminary research at Cisarua hot spring has been conducted by (Suharno et al., 2012) and measured that the hot spring was 50°C with discharge about 20 l/s. Additionally, travertine deposit was found surrounding the discharge (Suharno et al., 2012). The study of recharge area by analysing DEM/topographic map is also been done by Iqbal et al. (2018) which shows that the recharge area of Natar and Cisarua are lied at the southern part of Metro-Kotabumi Groundwater Basin and around Mt. Pesawaran, Mt. Betung, and Panjang.

The aim of this research is to identify and understand the characteristic of the geothermal fluid at Natar and surrounding area. Geothermal manifestations in the research area appear at the flat terrain topography which makes it interesting to be studied. Its appearance can be an initial deduction to determine the relation between Natar with the nearest geothermal system (e.g.: Ulubelu and Way Panas) which act as the outflow or Natar geothermal system is an independent system with flat topography without any influence from the volcano (non-volcanic geothermal system).

2. Methods

This research analyzes geochemistry aspect from several samples which are taken from the hot spring and groundwater (well). Thermal water samples are taken from Natar and Cisarua hot spring with total 4 samples. Meanwhile, groundwater sample is taken from the local well near Cisarua hot spring. These samples are then analyzed at PAIR-BATAN Laboratory Jakarta to determine the cation-anion content, (Li+, Na+, K+, Ca2+, Mg2+, Cl-, F-, SO42+, HCO3-), stable isotope D, 18O, Tritium, and 13C. The results of this analysis will be plotted on several ternary diagrams i.e. Cl-SO4-HCO3 (CSH), Cl-Li-B (CLB), and Na-K-Mg (NKM) for further interpretation. CSH diagram is used to determine the type of thermal waters, CLB diagram used to determine the similarity of the reservoir, and NKM diagram is used as geoindicator for mixing fluid with groundwater. Another aspect that can be obtained from geochemistry data is the estimated reservoir temperature using a geothermometer (Na/K, K/Mg, Na-K-Ca, etc.). By knowing the reservoir temperature, the reservoir depth can be estimated using statistical data on geothermal field drilling in Indonesia (Hochstein and Sudarman, 2008).

3. Geological Setting

Geology of the research area already mapped by Mangga et al. (1993) in Tanjungkarang quadruple with scale 1:250.000 (Fig. 1). The morphology of the research area is composed of the terrain and the foot of Mount Betung in the southern region (Fig. 1). Local stratigraphy in Natar and Cisarua MAP areas consists of Young Volcanic Deposits (Qhvp) and Lampung Formation (QTl). In addition, there are also metamorphic rocks of Trimulyo Marble (Pzgm) and igneous rocks of Branti Granodiorite (Kgdb). Mangga et al. (1993) described these formations as follows (oldest to youngest):

Trimulyo marble (Pzgm) consists of marble with schists intercalation. Grey-white marble, in some places greenish-grey which is composed of calcite-dolomite with granoblastic texture, massive and hard. This formation is metamorphosed regionally and is considered to be the core rock of Sumatra's metamorphic rocks.

Branti Granodiorite (Kgdb) consists of granodiorite and diorite from Early Cretaceous (87 ± 3 million) with medium grain, white-pink grey in color, granitoid with subhedral biotite. This unit is an intrusive rock in the form of small plutons but does not show contact with the wall rock which are located approximately 25 km north of Tanjungkarang.

Lampung Formation (QTl) is deposited in the fluvial-terrestrial environment has a Pliocene-Pleistocene age which is composed of rhyolite -dacite tuff, pumiceous tuff, and tuffaceous sandstone. Tuff is rhyolite-dacite in composition, white to brownish, volcanoclastic rock, and fractured. Pumiceous tuff, yellowish grey to greyish-white, medium-coarse grains, poorly sorted, composed of pumice and rock fragments. Tuffaceous sandstone, yellowish-white, medium-fine grains, poorly sorted, sub-rounded, pumiceous in some places, showing a crossbedding, generally composed by dacite. This formation has a thickness of about 200 m.

Young Volcanic Deposit (Qhvp) is composed of andesite-basalt lava, breccia, and tuff. The lava is Pleistocene and Holocene in age, blackish grey, aphanitic and porphyritic with plagioclase and augite phenocryst in the glass groundmass, with a little olivine. Breccia with blackish-grey colour, poorly sorted, angular, pebble-boulder size. Tuff is gray-brownish-brown in colour, composed of lava, glass and carbonaceous.

The geological structure in the research area is dominated by lineament trending northwest-southeast (Fig. 1) which is thought to be the cause of the emergence of geothermal discharge in the form of hot springs in Natar and Cisarua.

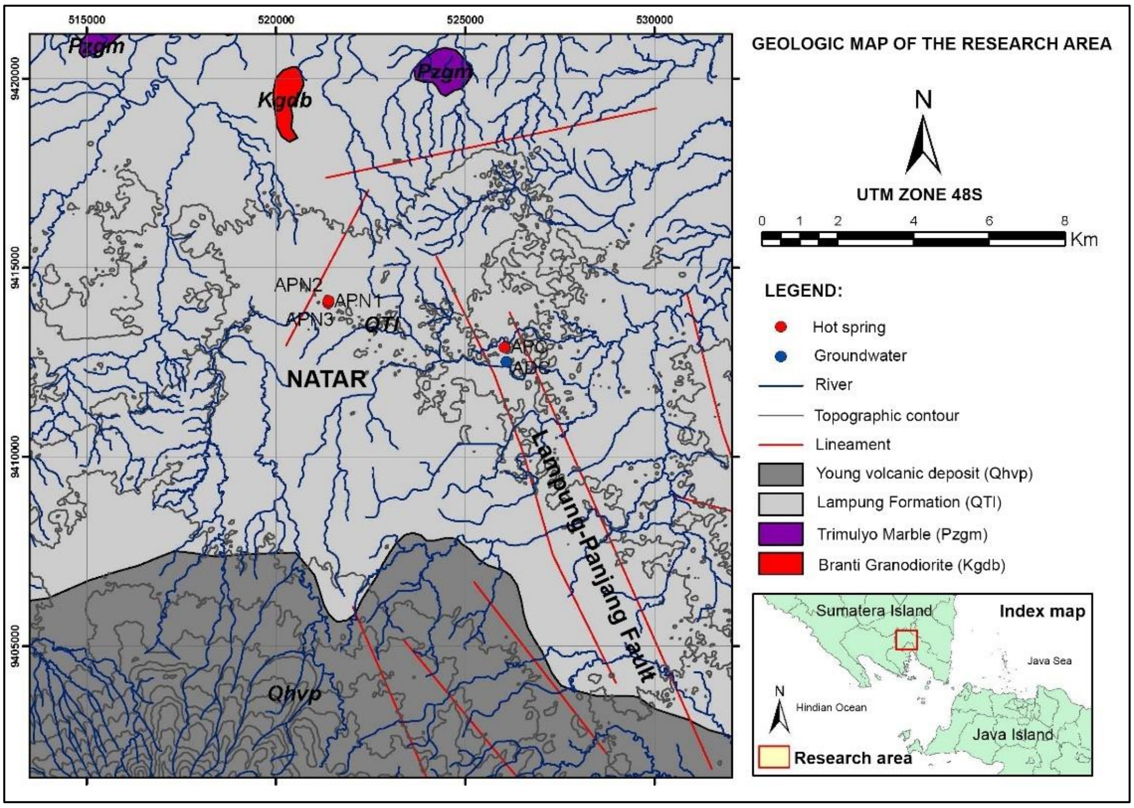

Fig. 1. Geologic map in Natar and surroundings (Mangga et al., 1993).

4. Result

Generally, the manifestations in Natar geothermal system are classified as warm-hot springs with temperatures ranging from 40-54°C and pH close to neutral. The description of manifestations is presented in Table 1. The results of water chemistry analysis in several samples are presented in Table 2 while Table 3 presents the results of stable isotope analysis. In general, all samples have the highest content in HCO3 with the content ranging from 208-396 ppm. Cl content in cold water is smaller than the sample of hot water while the Mg value in all samples is classified as similar.

In general, the results of the isotope analysis show differences in values that are not too significant at δ18O, δD, δ13C, and T (tritium). The differences in the 18O and D isotope values in each sample of thermal and cold water only ranged from 2.61 and 13.2 respectively (Table 3). Whereas at 13C and Tritium the value difference is smaller so that it can be classified still in the same group.

Table 1. Hot spring characteristics in the research area.

No.	Sample	Sampling Date	Debit	T water	T air	pH	Description
			l/s	°C	°C		
1	APN1	15 April 2018	~1	54	32	6,23	Clear, a little smell of sulfur, tasteless, there are bubbles of great intensity, manifestations concentrated in wells, appearance around manifestations in the form of organisms (mosses) that are on the walls of wells and orange well edges (Fig. 2a).
2	APN2	30 September 2018	~0,03	50	32	~7	Clear, odourless, tasteless, there are bubbles of great intensity, manifestations concentrated in 50 cm holes, appearance around manifestations in the form of organisms (mosses) and yellowish deposits around the manifestation hole (Fig. 2b).
3	APN3	30 September 2018	~0,12	47	32	~7	Clear, odourless, tasteless, there are bubbles of small intensity, manifestations are concentrated in wells, wells are right in the middle of a hot water bath, the appearance around the manifestation is an organism (moss) that is on the well wall (Fig. 2c).
4	APC	30 September 2018	~1	~40	32	~7	Clear, the smell of sulfur, brackish, there are 3 bubbles with moderate intensity concentrated in the well, the appearance around the manifestation is yellowish deposits (Fig. 2d).

Table 2. Water chemistry result.

No	Sample Location	Code	Sample type	Temperature	pH	Li^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	F^-	SO_4^{2+}	HCO_3^-
				°C						ppm				
1	Natar	APN	Thermal water	54,3	6,23	0,03	97,72	6,92	3,86	12,55	40,33	2,12	23,81	337,18
2	Natar	APN2	Thermal water	50	~7	0,02	120,11	3,81	44,79	15,93	35,33	2,26	20,81	396,36
3	Natar	APN3	Thermal water	47	~7	0,02	93,24	8,12	4,38	15,03	46,12	2,91	20,57	314,29
4	Cisarua	APC	Thermal water	~40	~7	0,02	98,43	5,29	15,77	15,42	38,90	2,47	20,11	330,16
5	Cisarua	ADC	Cold water	nm	~7	0,04	26,86	2,46	28,11	15,55	5,19	0,58	35,66	208,24

nm: not measured.

Table 3. Stable isotope analysis result.

Sample location	Code	$\delta^{18}O$	δD	$\delta^{13}C$	Tritium
		(‰) SMOW	(‰) SMOW	(‰) PDB	TU
Natar	APN	-4,97	-40,4	-5,18	2,86
Natar	APN2	-2,65	-27,2	nm	nm
Natar	APN3	-5,18	-37,4	-4,27	2,77
Cisarua	APC	-5,26	-40,1	-4,02	2,83
Cisarua	ADC	-3,27	-35,4	nm	2,37

nm: not measured.

(a) APN1

(b) APN2

(c) APN3

(d) APC

Fig. 1. Geothermal manifestation in the research area (APC: Cisarua, APN: Natar).

5. Discussion

5.1 Geoindicator

The CSH ternary diagram is used to classify geothermal water types. Samples of cold water and thermal water are then plotted on the diagram. From several samples that have been taken and analyzed, all of the samples are classified as bicarbonate water (Fig. 3). This type of bicarbonate water is formed by condensation of steam and geothermal gas into groundwater near the surface (Nicholson, 1993). It can be seen that the cold-water point is located lower than the hot water point (Fig. 3) which indicates that cold water has a higher SO4 content, lower Cl, and higher HCO3 compared to the thermal water. Geothermal fluids (steam and water) that rise to the surface have content of Cl (in the liquid phase) and CO2 (in the vapour phase) and then heated the groundwater near the surface and form steam-heated waters/steam condensates. Cl element which is carried from the reservoir adds Cl element which is in groundwater when mixed near the surface so that the Cl content in hot water is higher than cold water. The CO2 vapour that rises to the surface adsorbs H2O in groundwater and forms bicarbonate ions so that the content increases in the thermal water. While the higher SO4 content of cold water compared to hot water is caused by oxidation of the soil which contains many elements of sulfur (Miljević et al., 2013).

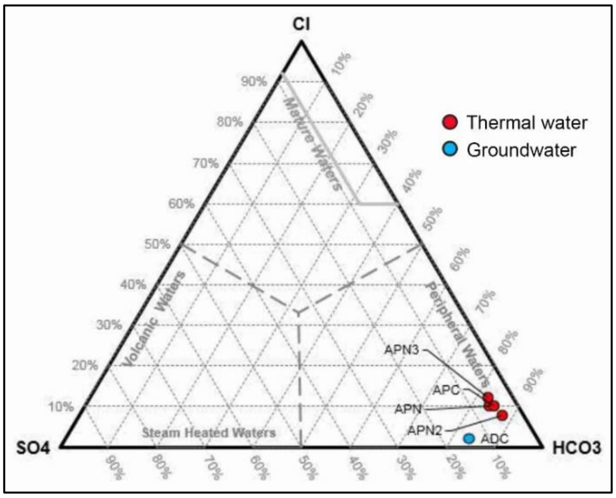

Fig. 3. CSH (Cl-SO4-HCO3) diagram to classify the type of water.

The CLB ternary diagram (Fig. 4) is used to identify reservoir similarities by comparing the conservative elements (Cl, Li, B, Br, As, Cs). Conservative or non-reactive elements tend to be in solution when the element is dissolved (Nicholson, 1993). In this study, boron content was not measured so that to determine the similarity of the reservoir only a comparison of Cl/Li elements was used. The four samples have similar Cl/Li ratios (Fig. 4) so that all manifestations come from the same reservoir/aquifer.

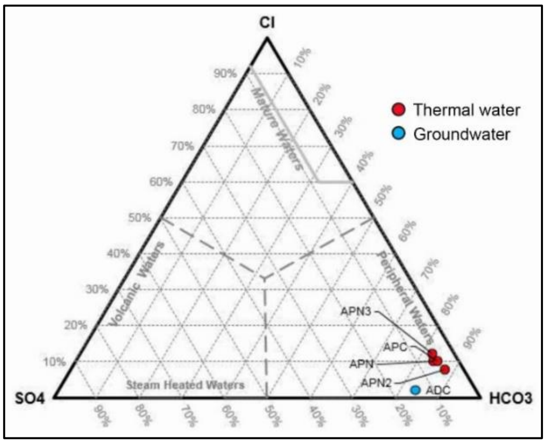

Fig. 4. CLB (Cl-Li-B) diagram to identify the similarity of the reservoir.

The content of Mg in geothermal reservoir fluids is relatively low, which is around 0.01-0.1 mg/kg (Nicholson, 1993), while the value of Mg in groundwater tends to be high. Thermal water samples in the study area belong to immature waters (Fig. 5) with relatively high Mg content which indicates that hot water samples have been mixed with the groundwater.

Plotting on the Piper diagram (Fig. 6) based on the concentration of dissolved ions in the samples ADN, APC, APN1, APN2, and APN3 shows two types of water types, namely Ca/Mg - HCO3 and Na+K - HCO3. Based on Clark (2015), Natar cold water (ADN) which has a type of water Ca/Mg - HCO3 indicates that the water is originating from shallow aquifers. In contrast to the thermal waters at APC, APN1, APN2, and APN3 which has a type of water Na+K - HCO3 which indicates that there has been a change between the alkali element and alkaline earth. This indicates the presence of water-rock interactions and different aquifer/reservoir layers between cold water (ADN) and thermal water (APN1, APN2, APN3, and APC).

5.2 Temperature and Reservoir Depth

The reservoir temperature is estimated by using several geothermometers such as Na/K (Fournier, 1979; Giggenbach, 1988; Nieva and Nieva, 1987; Tonani, 1980; Truesdell, 1975), Na-K-Ca (Fournier and Truesdell, 1973) and K/Mg (Giggenbach, 1988). From several calculations using the geothermometer, the authors conclude that the reservoir temperature in the Natar Geothermal System is 120-140°C.

The estimation of the reservoir depth is calculated by using statistical geothermal drilling wells in Indonesia proposed by Hochstein and Sudarman (2008). From the drilling data, Iqbal et al. (2016) obtained a quadratic regression trendline to see the relationship between the reservoir temperature and the reservoir depth (Fig. 7) and acquire the following equation:

$$H = -0{,}0257\, t^2 + 0{,}4446\, t + 31{,}248 \qquad (1)$$

where h is reservoir depth and t is reservoir temperature. By using reservoir temperature data that has been calculated previously, the calculation using Eqn. 1 produces a reservoir depth in the Natar geothermal system which is 285-400 m. Seeing from the regional geological map (Fig. 1), the Natar geothermal system is covered by the Lampung Formation which is dominated by tuff with a thickness of about 200m (Mangga et al., 1993). Lampung Formation was deposited above the unconformity of metamorphic rock which acts as a basement in the regional geology of Sumatera. Therefore, the Natar geothermal reservoir is thought to lie in the metamorphic rock (basement) which support by 13C isotope data from hot water samples which show that the hot water has undergone interaction with metamorphic-carbonate rocks (Trimulyo Marble Unit) under the surface (Fig. 8).

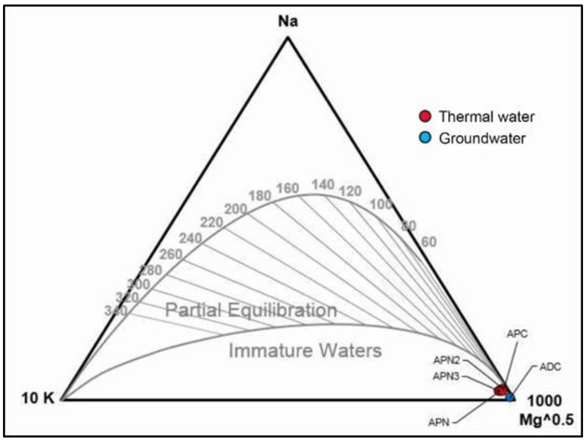

Fig. 5. NKM (Na-K-Mg) diagram.

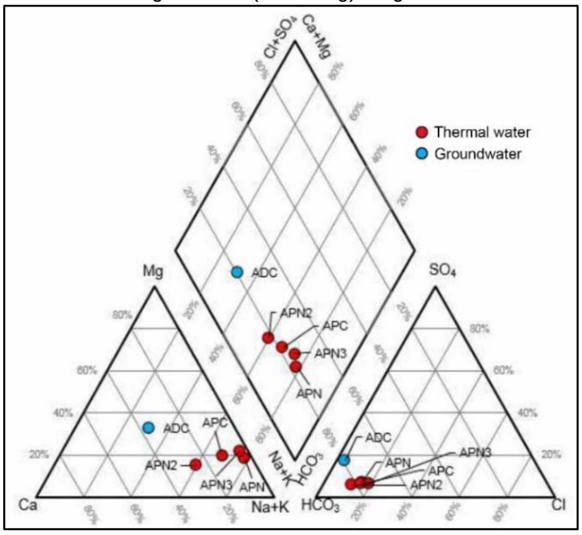

Fig. 6. Piper diagram.

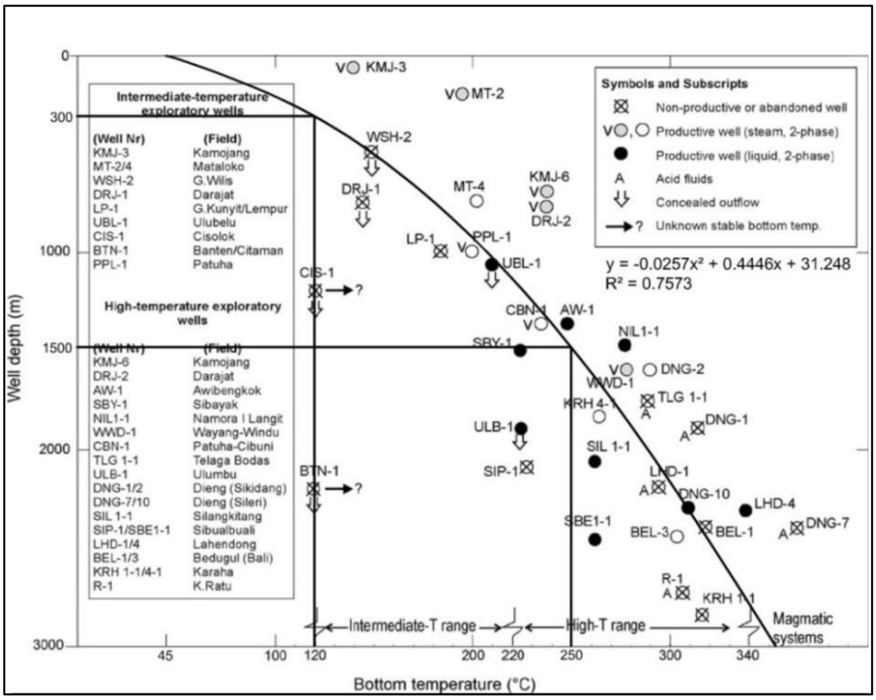

Fig. 2. Estimation of the reservoir depth using statistical data of geothermal field in Indonesia (Hochstein and Sudarman, 2008; Iqbal et al., 2016).

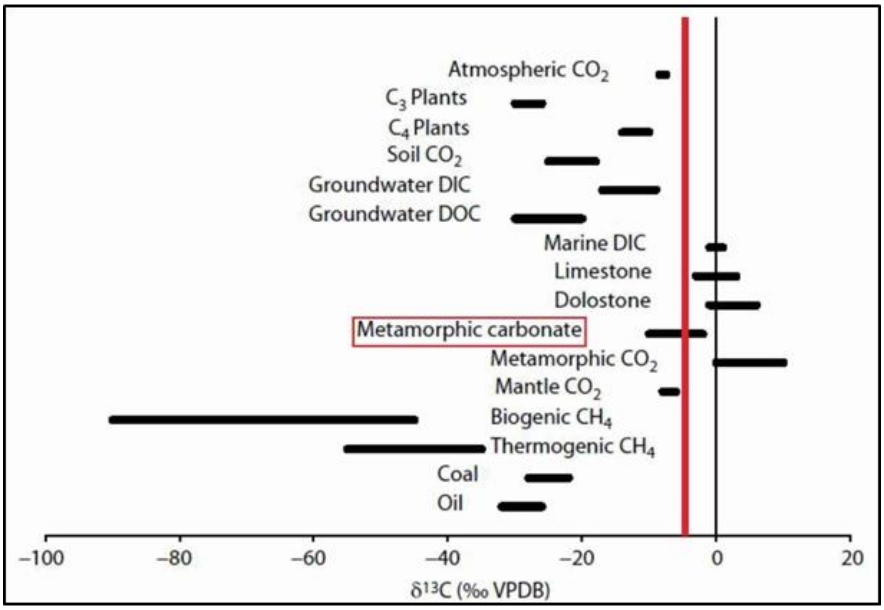

Fig. 3. Range of ^{13}C isotope values. ^{13}C isotope values of thermal water samples in the study area indicate that the thermal water has undergone interaction with metamorphic-carbonate/marble rocks (Clark, 2015).

5.3 The origin of thermal waters

Interpretation of stable isotope values D and 18O is carried out to determine the origin of the geothermal fluid. Plotting sample isotope values in the study area show that all samples are originated from meteoric water (Fig. 9). These data also support that the hot springs come from the groundwater that heated by the geothermal steam or steam-heated water because it has relatively similar isotope values.

Tritium analysis was carried out in the research area to measure the residence time of water since infiltrate until it discharges to the surface. Tritium analysis was carried out on four samples, namely; APN1, APN3, APC, and ADC. The tritium value of thermal water ranges from 2.77 TU (APN3) to 2.86 TU (APN1) while in cold water tritium value is 2.37. Based on Pujiindiyati (2007), the value of 2-8 TU tritium in areas with low latitude indicates that the water is modern groundwater which has only permeated <5 to 10 years ago. Tritium value in cold water is lower than hot water which indicates that the residence time of thermal water in aquifers/reservoirs below the surface is relatively longer than cold water (groundwater).

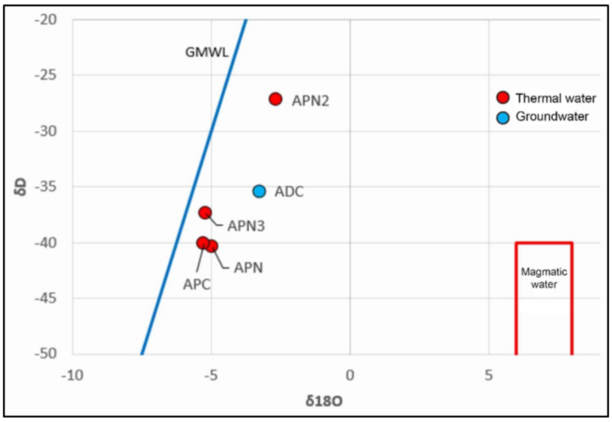

Fig. 9. D and 18O isotope values of thermal and cold water in the study area. Meteoric water lines using global values (GMWL/global meteoric water line) refer to (Craig, 1961). The range of isotope values of magmatic water is proposed by (White, 1974).

6. Conclusion

This research obtains several conclusions as follows:

1. Natar and Cisarua hot springs are bicarbonate type hot springs which are formed due to steam-heated waters.
2. Both hot springs come from the same reservoir, namely Natar Reservoir which has a temperature of 120-140°C with a depth of 285-400 m.
3. Geothermal discharge in Natar has undergone water-rock interaction with metamorphic-carbonate/marble under the surface.
4. Further research is needed to find the heat source from the Natar geothermal system by using geophysical methods such as gravity or magnetotelluric methods.

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